10 SURF Infrastructure, Assembly, and Integration

This section describes the surface and underground infrastructure improvements and additions needed at SURF in order to facilitate LZ assembly and installation. A detailed assembly and installation sequence for LZ is also presented here. Infrastructure at SURF includes the following: (1) surface laboratory space for assembly of the Xe detector (WBS 1.5) into the inner cryostat vessel (WBS 1.2); (2) staging space for scintillator veto tanks and scintillator (WBS 1.6), for the outer cryostat subcomponents (WBS 1.2), and other detector components; (3) secure storage space for Xe; (4) custom tooling for lowering the fully assembled Xe detector sealed inside the inner cryostat down the Yates shaft; and (5) modifications to the Davis Campus at the 4850L of SURF. These infrastructure elements are described below. Surface and infrastructure improvements are being funded primarily by the South Dakota Science and Technology Authority (SDSTA). The design of the infrastructure improvements has been a joint effort between the SDSTA engineering and technical staff, an external contractor and the LZ collaboration. The firm Leo A. Daly [1] is under contract to SDSTA for the detailed design of the surface and underground infrastructure improvements. The final design is complete.

10.1 Surface Infrastructure

Figure 10.1.1: Aerial view of the SURF site showing the locations of the Surface Assembly Laboratory and the Surface Storage Facility.

The principal components of the surface infrastructure specific to LZ are: (a) the Surface Assembly Laboratory (SAL), (b) the Surface Storage Facility (SSF), and (c) office and meeting space at the SDSTA administration and education buildings. Office and meeting space already exists for ongoing experiments at SDSTA;

general improvements to these capabilities will serve the broader experimental community at SURF, and are not described here. The locations of the SAL and the SSF at SURF are shown in Figure 10.1.1

The SAL was utilized for the assembly of the LUX detector and for operation of LUX in a water tank located in the SAL. Significant upgrades to the SAL are planned for assembly of the LZ detector and are described later. The most significant improvement to the SAL is the addition of radon-reduced air-handling capability. A new building to house a system that provides reduced-radon air to the SAL will be constructed between the SAL and the SSF. The SSF is currently used for general storage and modest interior improvements were made in order to be used for storage and disposition of components during LUX decommissioning, which began in September 2016. These improvements will also provide staging space for LZ components.

10.1.1 Surface Assembly Laboratory (SAL)

The SAL building is a wood-frame structure with four levels: the surface level and levels −1, −2, and −3, which are successively deeper below the surface. This building was renovated for LUX assembly and testing and has a sprinkler system, HVAC, and 220 kVA installed electrical capacity. An existing cleanroom of 2,900 ft^3 will be used for cleaning and staging metal parts and bagged PTFE parts prior to Xe detector assembly in the low-radon cleanroom, and for other assembly tasks not requiring a low-radon environment. A new low-radon cleanroom will provide workspace beneath an existing monorail and over a pit in Level −1. The new cleanroom will be connected, but separated by doors, from the existing cleanroom and will have a separate air-handling system. Transport of the detector will be facilitated by rolling it to the building shipping dock. The layout of the SAL is shown in Figure 10.1.2. The design of the new cleanroom is based in part on the design of a low-radon cleanroom in place at SDSM&T [2]. The design goal for this new cleanroom is <1 Bq/m^3 (unoccupied). The cleanroom is under fabrication by a commercial vendor to specifications set by SDSTA and the LZ Project.

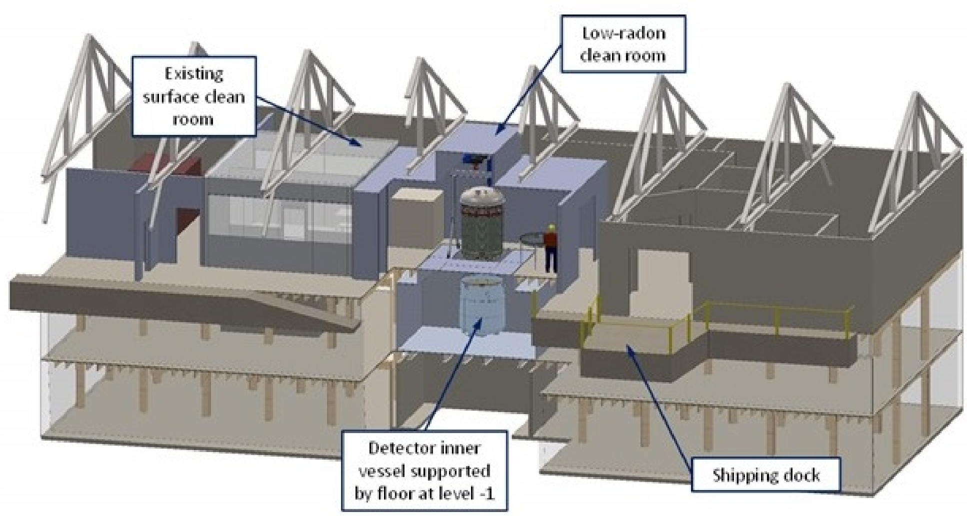


Figure 10.1.2: The Surface Assembly Laboratory.

10.1.2 Radon-reduced Air System

Radon is one the highest-risk contaminants for low-background experiments because it can easily escape from bulk material and quickly diffuse into active parts of the detectors. The innermost materials and parts of ultralow-background experiments must be manufactured or assembled in a radon-suppressed atmosphere.

Final assembly of the LZ time projection chamber (TPC) will occur in a cleanroom in the SAL, which has a radon-reduced air system.

Figure 10.1.3: A picture (October 2016) of the additional building being constructed to house the radon-removal system (RRS).

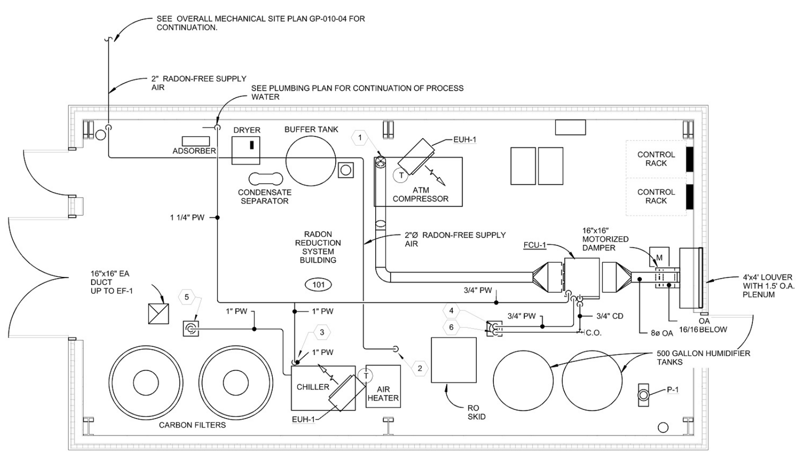


Figure 10.1.4: Plan view of RRS Building.

Carbon adsorption is the preferred technique for removing radon from air and has been effective for varying degrees of radon contamination, from as low as a few mBq/m^3 for low- background experiments to levels as high as $\sim$100 Bq/m^3. The surface air radon level at SURF is expected to be in the range of $\sim$20 Bq/m^3. The LZ detector assembly cleanroom will be designed with a radon-reduction factor of greater than 1,000. It will be flushed with radon-reduced air at a flowrate of about 250 m^3/h, which is produced by compressing, drying, cooling, and pushing the air through two 1,600 kg activated-carbon towers. Our plan is to use a commercial unit provided by ATEKO, which has developed and built large commercial radon-removal systems for other sensitive underground experiments. These units are capable of reducing radon concentration in the air by a factor of greater than 1,000. The fabrication of the LZ unit has begun for delivery in Spring 2017.

The process is based on compression, cleaning, and drying (dew point $-70\,^\circ$C min.) of air, cooling to $-55\,^\circ$C, adsorption of radon from air on activated carbon at $-50\,^\circ$C at approximately 8 bars of pressure, followed by heating and pressure reduction of air to ambient pressure and temperature. A new building is being constructed to specifically house this system, and will be located between the SAL and SSF on an existing concrete pad illustrated in Figure 10.1.3.

A plan view of the building, showing the location of key components, is illustrated in Figure 10.1.4.

10.1.3 Surface Storage Facility (SSF)

Short-term storage and staging of equipment needed for experiment assembly including the large scintillator tanks - will be facilitated by upgrades to an existing building next to the SAL. The SSF has a large high bay with approximately 445 m^2 (4,800 ft^2) of lay-down space under a 40-ft-wide 10-ton bridge crane. Hook height on the bridge crane reaches 7.3 m (24 ft). Handling of equipment will also be facilitated by three wall-mounted jib cranes rated at 1 ton, 2 tons, and 3 tons, respectively. Truck entry to the building is via a 4-m (13-ft)-wide $\times$ 5-m (16-ft)-tall entry rollup door. A structure within the SSF has been built to first house materials and equipment resulting from the removal of LUX from the Davis Cavern and decommissioning, and then LZ components. A view of this building showing scintillator barrels (about 50 % of the total) and transport boxes containing the outer detector acrylic vessels is shown in Figure 10.1.5.

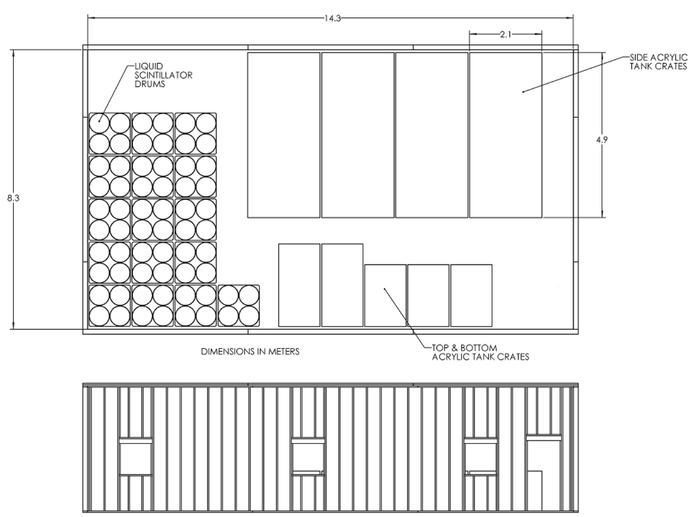
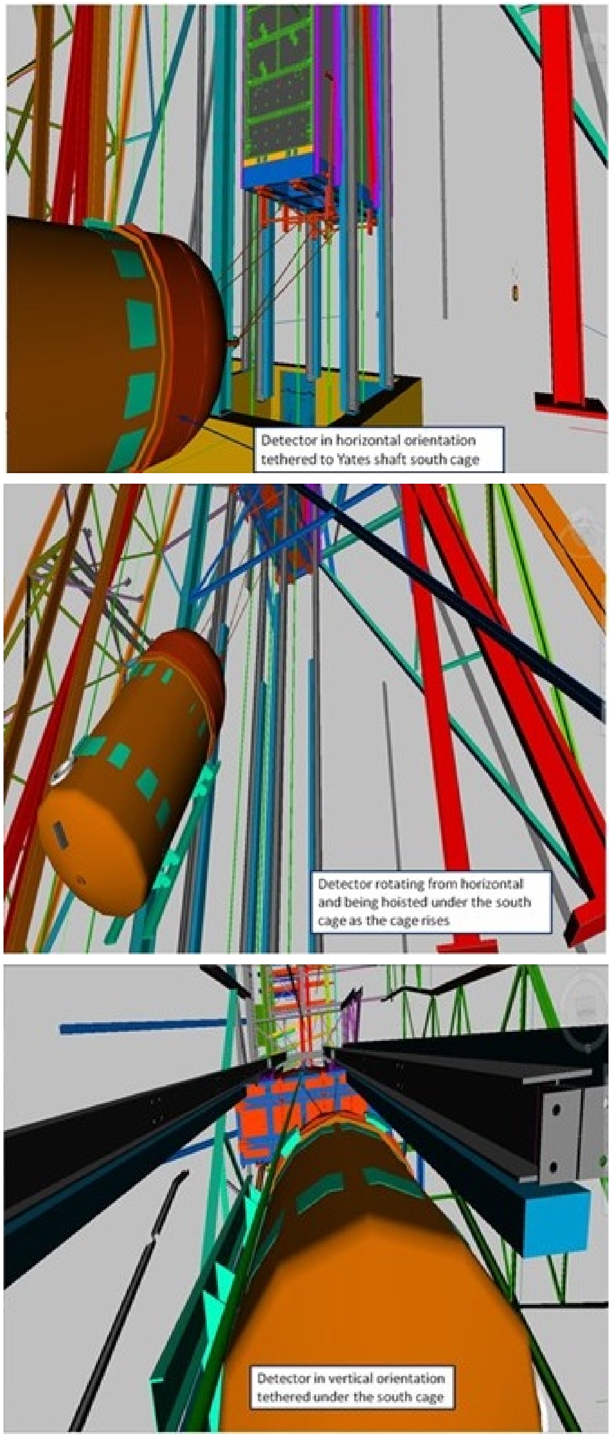


Figure 10.1.5: Building constructed for staging LZ detector components.

10.2 Yates Shaft Infrastructure and Custom Transport

The LZ TPC inside the inner cryostat will be transported from the SAL to the Yates headframe in a horizontal orientation. The transport method will be similar to the successful transport of LUX from the same building to the headframe. A large telehandler was used, along with continuous monitor of orientation and G-forces. LUX was transported in the Yates cage but the LZ assembly will be slung under the cage, given its larger size. The LZ detector/inner cryostat will be placed on a custom transport frame.



In the first image, the LZ detector lies horizontally at the shaft entrance and the cage bottom is 6 to 7 feet above the floor. Crews will cover the shaft by installing a work platform and attach the slings to the bottom of the cage. These are also attached to the top of the LZ detector. The platform will be removed and the cage hoisted to remove slack. Another wire rope control line from a winch is attached to the bottom of the detector.

In the second image, the hoist is lifting the LZ detector in the shaft to its vertical position. The control line mounted on the detector bottom will maintain tension in order to control the swing into the shaft. Even though not fully in the shaft, the bottom of the custom transport frame is off the ground. Once hoisting is in process, it will not be stopped unless a difficulty arises. The entire procedure is short-lived.

In the third image, looking almost vertically. Here, the detector is hanging vertically. It will be positioned properly in order for the crew to attach the bumpers or guide shoes for clearance and centering during shaft transit. After inspections, a crew will man the cage and watch as it travels underground, being lowered at a rate of 0.7 ft/s.

Figure 10.2.1: The transport method of the LZ TPC inside the inner cryostat will be similar to the successful transport of LUX from the same building to the headframe.

Once the detector/inner cryostat assembly arrives at the Yates headframe, the assembly on the transport frame will be lowered in the Yates shaft, as shown in Figure 10.2.1. Lowering the assembly on its transport cart slung under the Yates cage will take some hours. A crew member will accompany the assembly in the Yates conveyance, as was done for LUX. The assembly and transport cart will be extracted from the Yates shaft at the 4850L and rotated back to the horizontal orientation. A trial lowering in the Yates shaft of a mockup of the transport frame and the cryostat has been completed successfully.

10.3 Underground Infrastructure

A plan view of the Davis Campus is shown in Figure 10.3.1. After arriving on the 4850L, the detector will be transported to the Davis Cavern via the Primary Access Drift, passing by the room housing the MAJORANA detector, as depicted in Figure 10.3.1. That is the same access-way utilized for transport of the LUX detector. The larger LZ inner cryostat can be moved through the same space by temporarily removing short segments of the Davis Campus HVAC air-supply ducts to allow for sufficient clearance. All access doorways are sufficiently large to allow for detector passage. Entry to the Davis Cavern via the Primary Access Drift allows the transporter design to take advantage of the 8,100-lb maximum floor loading afforded by design of the Davis Cavern structural steel. It would also be possible to transport the inner detector in the drift that passes by the LN storage room, but this would require the removal (and later replacement) of a wall between the drift and the Davis Cavern.

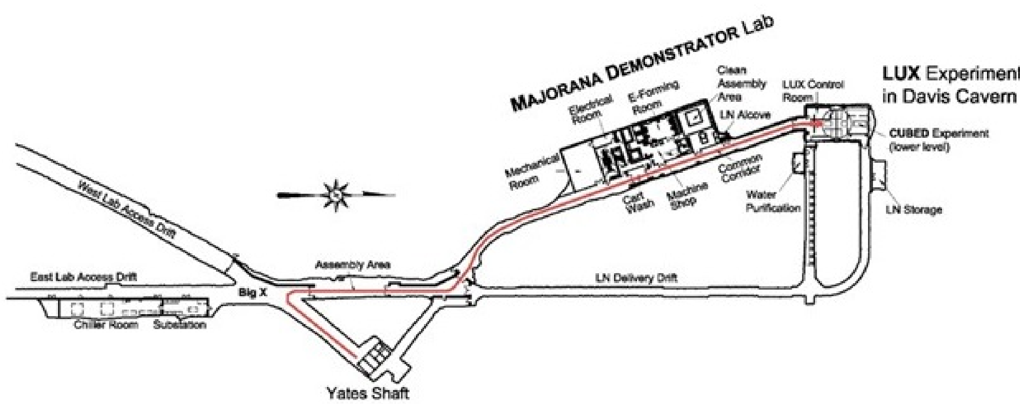


Figure 10.3.1: Plan view of the Davis Campus at the 4850L.

LZ will take advantage of design features built into the Davis Cavern to allow for deployment of a larger detector than LUX. A 102-inch-diameter flange is built into the 70,000-gallon water tank. Additionally, the redundant 50-ton water chillers and the Davis Campus 1,500 kVA substation were implemented with a large future detector in mind.

Figure 10.3.2 shows an isometric view of the LZ deployment in the Davis Campus. Xenon storage cylinders will be securely deployed in a newly upgraded portion of the present LN storage room access drift (shown in the lower-right corner). Currently, this is an unfinished area that has been used for rock- moving equipment and storage. SURF will upgrade this area by providing concrete floors and covered walls while also closing off the space to allow for flow-through ventilation. Ventilation will be adequate to mitigate potential oxygen - deficiency hazards that could occur in the event of a release from one of the Xe storage cylinders. The Xe cylinders are more thoroughly described in Chapter 6.

The LN storage rooms and control rooms used for LUX will be largely reused. LZ will utilize a similar scheme for LN storage tanks until a second cryocooler is secured for long-term operational flexibility. These tanks will supply makeup nitrogen to the cryocooler, assist with transient startup effects, purge gas for the water purification system, and provide some buffer against short-term power interruptions. The control room is expected to remain unchanged, providing minimal office space for underground workers during assembly, commissioning, and data taking.

The ventilation duct that exhausts the LN storage room will be modified to also ventilate the Xe storage room. New supplemental ducting and a fan added to the existing ventilation will provide fresh air flow.

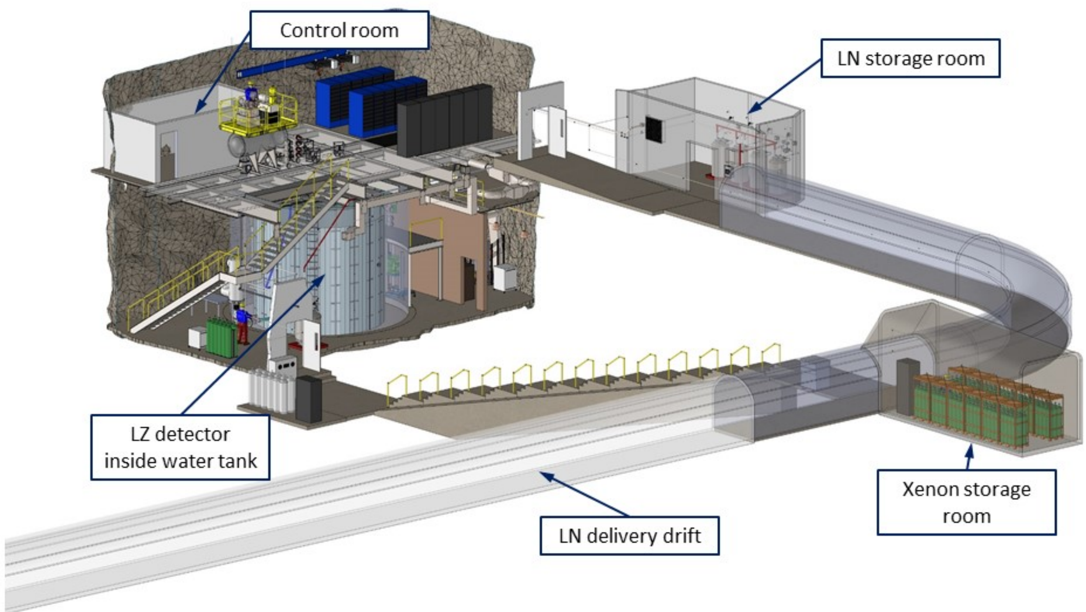


Figure 10.3.2: Overall layout of LZ in the Davis Campus.

Figure 10.3.3 depicts a close-up view of the Davis Cavern showing supporting infrastructure installed. Key elements include data acquisition (DAQ) cabinets, a cryocooler to support cooling thermosyphon lines, a platform that interfaces to the PMT and sensor cable breakout, a XE purification tower for circulation heat exchange, and Xe circulation/storage equipment deployed both in and above the current low-background counting rooms in the lower Davis Cavern.

To facilitate deployment of a larger number of DAQ racks and cryocoolers on the deck of the upper Davis Cavern, SURF will decommission and remove the existing cleanroom to open up floor space. A new platform deployed near the PMT cable breakouts will also serve to significantly increase the effective floor space in the cavern.

All other Xe circulation, storage, and recovery equipment is co- located in space behind block walls previously utilized for low- background experiments. Included are the Xe recovery compressors. These large 480 V units are positioned near existing in-cavern power panels and also the low-pressure/higher-loss suction side of the Xe gas system.

The Davis Campus is fed from a 1,500 kVA substation. The substation is presently loaded at approximately 60 % during worst-case conditions, and has ample reserve capacity to accommodate the projected LZ electrical load of about 115 kW (an increase of about ∼75 kW from LUX). The campus has a 300 kW backup generator that supplies the air- handling systems, communications, facility control and alarm systems, and egress lighting for up to 48 hours. An additional 40 kW generator will be installed to provide backup power for LZ.

A system to provide reduced-radon air during critical assembly steps inside the water tank will be located underground just outside the entrance to the clean area of the Davis Campus in an existing space. This system will provide reduced-radon air for the few months of critical connections to the Xe detector and possibly later. Air will be piped from this system to the water tank. The baseline plan for this system follows closely from a similar system constructed at the South Dakota School of Mines and Technology [2].

Because the water tank installed for the LUX experiment was designed to be able to accommodate a much larger experiment, the modifications required for LZ are modest.

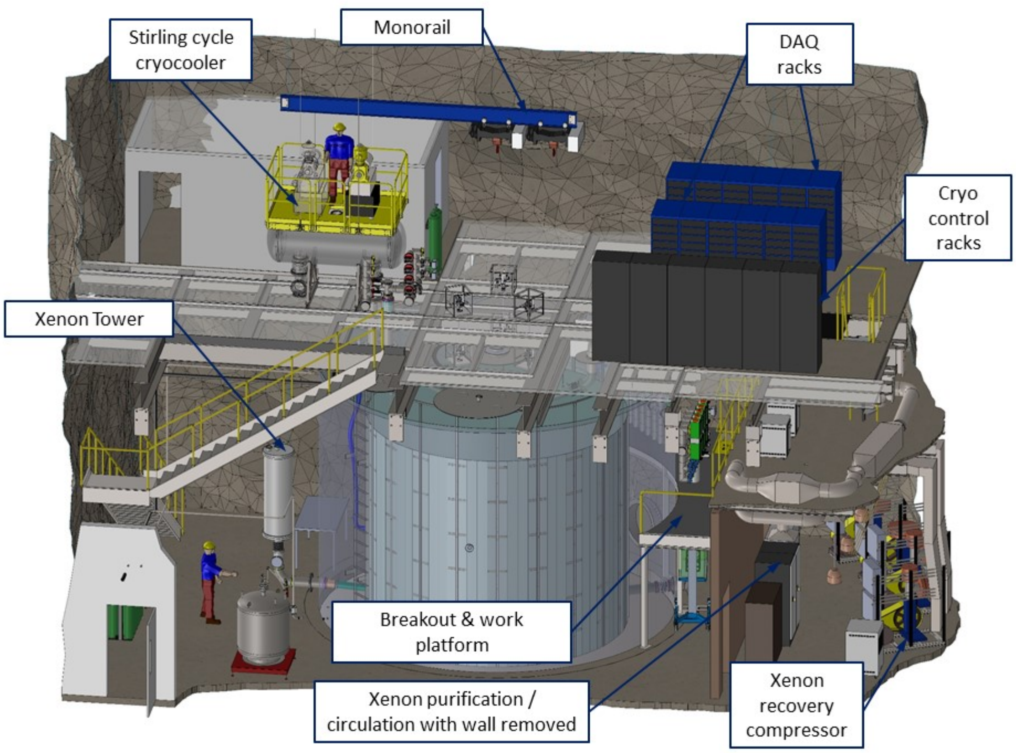


Figure 10.3.3: LZ and related support systems in the Davis Cavern.

Mounting plates will be added to the tank floor for the LZ detector along with mounting points for the four side scintillator vessels. At larger radius, mounting points will be installed for the outer detector PMT ladders. In addition, a support for the lower conduit that connects the detector to the LXe tower and PMT cable breakout will be installed.

The detector HV system for LZ requires a feedthrough in the top of the water tank. In addition, two penetrations of the tank wall are needed for routing the conduits that connect the detector to the LXe tower and the PMT cable breakout. Two neutron tubes will be installed for the neutron calibration system, and that tube will be filled with water for normal running and nitrogen for calibration. The top of the water tank will also have several feedthroughs to accommodate thermosyphons, detector cables, source tubes, scintillator lines, water PMT cables, LED flasher cables, and vacuum pumping.

10.4 Integration and Assembly

This section describes the effort to integrate work at the subsystem level into a coherent design that meets the science requirements and that will result in an operational detector at SURF. A detailed assembly sequence is presented. While the overall scope of integration and assembly is contained in WBS 1.9, significant resources from every subsystem are required. Much of this effort comes from the distributed pool of engineers working for subsystems at many institutions. Coordination of this engineering effort is part of the integration task.

10.4.1 Integration

For LZ to achieve its science goals, it uses primary requirements that define what the subsystems must do; subsystem requirements drive more specific design specifications (see Chapter 12). The subsystems must be safe, affordable, timely, compatible with the other subsystems, and possible to assemble and operate with the available infrastructure. The Integration Group provides the necessary management, engineering, design, organizational tools, and administrative effort to assist all subsystems in completing the LZ design. Phone meetings and technical workshops help identify interface issues and hidden constraints created by design choices in other subsystems. An interface matrix is used to record and highlight interfaces between WBS areas. Interface Control Documents (ICDs) are authored by the key driver of the interface and reviewed and approved by all stakeholders. The Integration Group maintains CAD models of the overall LZ detector and of the Davis Campus. This helps define physical interferences and design gaps that are not adequately covered. At integration meetings, engineers from each subsystem, and many scientists, share ideas to help with some of the more difficult design challenges.

The Integration Group develops general standards and controls, such as engineering document standards to be used project-wide for CAD file exchange, engineering drawings and design notes, specifications and procedures, controled Technical Documents (CTDs), technical change (TCs) documents, and a document numbering and organization system. The Integration Group defines component reference names and an overall coordinate system for the experiment. The group maintains a cable and feed-through list with the help of the subsystem management. A key parameters list is maintained as a reference for design, modeling, and science.

As designs mature, they must be documented and reviewed. The Integration Group works with project and subsystem management to arrange and execute design reviews at appropriate times. Conceptual Design Reviews evaluate whether the design meets the requirements, interfaces have been identified and successfully coordinated, and engineering details are sufficiently developed to proceed. Preliminary Design Reviews focus on manufacturability, cost, schedule, risk, and safety. Final Design Reviews ensure that documentation and drawings are complete and the fabrication plan fits within project budgets and timelines. All LZ systems have completed Final Design Reviews. Production Readiness Reviews for WBS 1.2, WBS 1.5 (PMTs), and parts of WBS 1.6 (liquid scintillator production and acrylic vessels) have taken place.

LZ is being assembled and installed in an underground area administered by SURF. Integration includes working with SURF to be sure the infrastructure is adequate to support assembly, installation, and operation of the LZ experiment. SURF engineers are tasked with design and execution of infrastructure projects to support the LZ project. The Integration Group coordinates communication of requirements with SURF and the detector subsystems.

The overall planning of the on-site assembly and installation of the detector at the Davis Campus is part of the integration effort. This work includes defining the sequence of steps to put the detector together, creating a schedule for this work, and developing an understanding of the resources needed to accomplish it. Subsystems support this effort by providing details for handling components and aiding in resource and schedule development. Subsystems also develop detailed work procedures that technicians can follow for cleaning, assembly, and testing.

10.4.2 Assembly

The LZ assembly will happen in three stages—off-site subassembly, surface assembly in the Surface Assembly Lab (SAL), and underground assembly in the Davis Campus—with transportation between stages. The general strategy is to do as much work as practical off site at universities and national laboratories, where highly skilled, specialized labor can easily work with students and scientists. This also reduces travel costs. Parts delivered to the site will be tested, clean, and ready to use, with a few exceptions. The development of detailed delivery requirements and procedures, particularly cleanliness relevant to achieve the low-radioactivity needed, is under active development. A database and electronics logging tools will be used to track the location and status of parts and subassemblies, from initial fabrication through delivery to SURF, and up to assembly into the final detector. Assembly workers will check that the part has been approved for radioactivity, cleanliness, and function before using it on the detector.

Xe PMTs will be assembled, tested, and characterized prior to delivery to SURF. The PMT vendor will do some QA testing, but burn -in, final electrical characterization, and cold testing of each PMT will be done by LZ. Assembly includes connecting a PMT base to the PMT, attaching polytetrafluoroethylene (PTFE) reflectors, and final cleaning. Because they have PTFE as a reflector, the assemblies must be kept under a nitrogen purge during storage and shipping to prevent radon contamination. Internal PMT cables will have a pin-and-socket connection at both ends. They will ship separately and be routed to the PMTs after the PMTs are installed on the support arrays. The warm end of the cables will be connected to the feed-throughs mounted in flanges after the cables are routed. The cables must be kept clean and under nitrogen purge during storage and shipping because they contain fluorinated ethylene propylene (FEP) as the primary insulator.

The tested PMTs will be placed into the titanium PMT support structure, including preliminary placement and routing of the cables. The baseline plan is to do this work in a cleanroom at Brown University. The titanium arrays will be mounted in the two "PMT Array Lifting And Commissioning Enclosures" (PALACE – see Section 3.4.5), a multipurpose light- and gas-tight enclosure. The PALACE will be opened for PMT, reflector, and cable placement, and then closed and purged with nitrogen between operations and during testing. This work will create an upper and lower populated PMT array. The PALACEs will also be used to protect the arrays during shipping. The upper skin PMTs will be mounted into teflon trays that attach to the sides of the TPC. This work will be done in the reduced radon environment of the SAL clean room at SURF. The lower skin PMTs will be attached to a titanium support that is mounted to the bottom of the ICV. This work will also be done in the SAL.

The wire grids for cathode, gate, anode, and PMT shields will also be manufactured off site. The grids will be cleaned, inspected, packaged, and shipped to SURF. The packaging must keep the wires clean from any debris and protect the fragile wires from shock during shipping. Boxes of the same design as the PALACEs will be used for grid storage, shipment, and testing to save on design and manufacturing cost. Inspection procedures after fabrication and after arrival at SURF are under development and will be guided by experience in the system test at SLAC (see Chapter 3). These could involve automated optical inspection and voltage testing in gas.

The field-grading region of the TPC is made from conductive metal rings, insulating PTFE spacers, and resistors. These parts will be fabricated by vendors and then inspected and cleaned off site at LBNL before shipping to SURF. Radon exposure of completed PTFE parts will be minimized after final machining. They can be stored and shipped in nitrogen-filled metalized bags.

The cryostat will be manufactured in Italy as fully tested and cleaned code-stamped vessels under contract with the Imperial College. The fabrication vendor has the responsibility for final design, fabrication, testing, cleaning, and shipping to SURF. The inner and outer vessel will be shipped separately (not nested) in nitrogen-filled sealed bags from the cleaning facility. Receiving acceptance for the cryostat will include visual inspection for any shipping damage, separate assembly of each vessel, and vacuum leak-checking with helium. Rate of rise leak checking of the double O-ring seals will also be performed to get a baseline rate of rise for each joint. The reflective PTFE liner for the inner vessel will be attached to the inner cryostat vessel wall in the SAL. The plan is to suspend the bottom of the inner cryostat upside down in the vessel-assembly area and to access the inside of the vessel from underneath with a manlift. This will allow a worker to tile the inside while standing on a stable surface. The bottom skin PMT array will be installed into the bottom of the ICV. The ICV will be sealed after the line is installed. A radon emanation test of the lined ICV can be performed both to discover if there are any large radon issues and to establish the emanation from this part of the assembly so it can be compared to the emanation of the full assembly later.

The HV umbilical will be delivered from LBNL as a clean, tested, and sealed assembly. The heat-exchanger tower subassembly will be built, cleaned, and tested at the University of Wisconsin Physical Sciences Lab, and transported as a sealed assembly. The Gd-LS acrylic tanks will be manufactured, cleaned internally, tested off site, and shipped in protective packaging. They will be stored in the SSF. The outside of the Gd-LS tanks will be cleaned on site, underground. The ladders, PMTs, and Tyvek reflectors of the outer detector will be shipped separately.

It is unlikely that the timing of delivery can match the time when each piece is needed. The SSF is the identified storage location at SURF. A temperature-controlled storage room has been built in the SSF to store the Gd-LS and the acrylic tanks.

The subassembly work and transportation described above will primarily be the responsibility of the subsystems. Once things arrive at SURF, primary responsibility shifts to the Integration and Installation Team (WBS 1.9). The plan is to work with SURF to hire a pool of local technicians to perform much of the work. This pool will include experts in cleaning, vacuum, rigging, and mechanical assembly. A lead technician will handle managerial supervision and work direction, but technical supervision will be supplied by engineering and scientific staff. An LZ engineer will be on site to coordinate the work and provide technical oversight. Experts from subsystems will be on site during assembly of their subsystems. Existing SURF engineering and technical personnel will also provide support. Worker training and work control will be performed as part of the SURF safety program.

On-site assembly starts above ground with assembly of the TPC. Cleanliness is critical for this assembly work, both to reduce radioactivity backgrounds in the detector and to control particles that could cause field enhancements and reduce operating voltage. This work will be done in the SAL at SURF with a large reduced-radon cleanroom, described previously. Figure 10.4.1 shows the major steps of assembly in the SAL. The first step is receiving and inspection of the parts and subassemblies. Clean parts destined to enter the cleanroom will be shipped in triple bags. The first bag will be removed in the receiving area to keep dust and dirt out of the cleanroom area. The second bag will be removed in a soft-walled semi-cleanroom at the entrance to the cleanroom. The third bag will be removed inside the cleanroom after the particle count in the room has returned to normal after opening the door. The goal of the inspection is to ensure that the parts have not been damaged in shipment and that they will meet functional requirements. This includes cleanliness. The PMTs in the arrays will be tested to ensure they were not damaged in shipment. The grids will also be inspected.

The next several subsections describe the various stages of assembly. Each subsection concludes with a description of the suite of checkouts that will be performed prior to declaring the stage complete. Final definition of these checkouts is a crucial aspect of the assembly and will be made by WBS 1.9 in close consultation with the relevant subsystem owners.

10.4.2.1 TPC Assembly (Steps SA2 – SA6)

The assembly will start with the lower PMT array (see Chapter 3 for descriptions of the components referenced here) The lower PMT array will be set upside down on a ring shaped cart for initial assembly. The cart will have telescoping legs and locking wheels that allow adjustment to a comfortable working height and easy movement into an extra-clean storage garage. Eighteen skin 2-in PMTs will be connected to the titanium truss of the lower array. Xe return liquid distribution tubing and manifolds will be mounted and dressed. Loop antennae and temperature sensors will then be placed and cabled. The fully populated bottom subassembly will be rotated 180° and set back on the ring cart. A layer of arc shaped PTFE segments is screwed to the titanium support plate and then the PMT guard grid is placed on top of the PTFE. The reverse field-grading assembly composed of arc shaped PTFE segments and complete metal rings will be assembled onto the PMT array next. The parts are held together with axial PEEK screws that pass through a counterbored hole in the top PTFE part, a through hole in the titanium field shaping ring, and into a PEEK nut press fit into a coutnerbored hole (farside) in the bottom PTFE part. Leads from resistors that fit into pockets in the PTFE will be attached with screws to electrically connect the metal rings as they are stacked. When the reverse field region has been stacked to the correct height, The cathode grid is installed on the top of the stack. An additional layer of PTFE segments is placed on top of the cathode to allow connection to the forward field shaping subassemblies. The completed bottom subassembly will be stored in the garage when it is completed. Subassemblies are also stored in the garage whenever active work is not being done on them. This will reduce contamination of surfaces with dust. Sections of the forward field-grading assembly will be built on similar carts with ring shaped tops. The open support structure is designed to allow airflow through the pieces being assembled so less dust will accumulate on the work pieces. The forward field PTFE segments and rings are held together with radial pins. This allows the assemblies to be joined with only access from the outside. There will be four forward field subassemblies. The extraction region will be assembled at LBNL and shipped as a subassembly consisting of the weir trough, anode grid, gate grid, and a few layers of field shaping rings. The extraction region sub assembly will be mounted to a similar cart and the upper PMT array will be rigged in place over it. The extraction sub-assembly will be by connecting to the titanium plate of the upper array assembly. The 93 upper skin PMTs will be attached to the outside of this assembly. The cables from these PMTs will be carefully dressed with the other PMT cables. Voltage-control cables will be connected to the grids. Loop antennas, temperature sensors, and position sensors will then be placed and cabled. The completed extraction region subassembly will then be stored in the garage.

The full TPC will be assembled by moving carts holding sections under one side of the monorail, lifting the sections off the carts with the monorail crane, transporting them to the other side of the monorail, and lowering them onto the stack. The sections will be connected with PEEK radial pins. Before a subassembly is lifted, it will be inspected and tested for dust accumulation. This test and possible cleaning mitigations are under development. The assembled TPC will undergo a series of tests to ensure light-tightness of the field-grading cylinder, and function of all PMTs, HV grids, resistor network, and sensors.

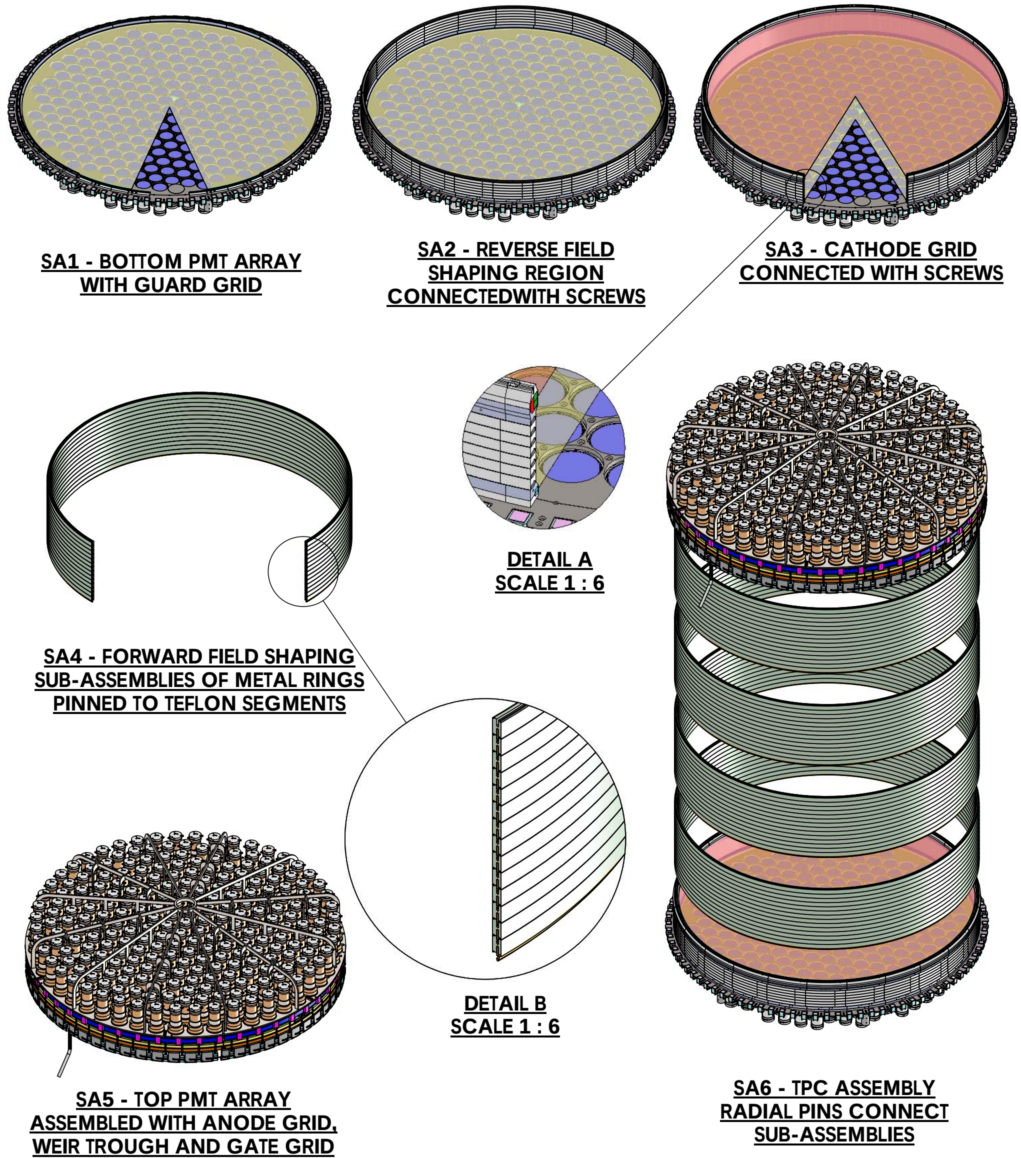


Figure 10.4.1: TPC assembly forms subassemblies of the lower PMT array with reverse field region and cathode grid; the upper PMT array, anode grid, weir trough and gate grid; and four short stacks of field shaping grids. These are then combined into a complete assembly

10.4.2.2 TPC Insertion into Cryostat with Fluid and Electrical Final Routing

The inner cryostat vessel (ICV) will be staged in the lower level of the cleanroom under a removable grated floor. The first step of insertion is to remove the lid of the ICV and raise it so the top flange is a few inches above the floor. The TPC will then be lifted with the hoist on the monorail, transported on the monorail over the ICV, and lowered into the ICV. Guide bars will be attached to the sides of the ICV and go vertically up to the top of the TPC to help guide the TPC as it is lowered. During this process, the PMT and sensor cables coming from the lower PMT array will be routed through the central port in the bottom of the inner cryostat. Xe fluid circulation lines also routed through this port will have been placed into position earlier, but may need adjusting and securing as part of the cable routing. Access for this operation will be through the HV connection port and the bottom port of the vessel. The three Xe tubes from the weir trough must be routed to the ports in the inner cryostat wall. These tubes are PTFE bellows that will initially be pointing straight down and then guided into the ports as the TPC is lowered. The TPC is supported on six posts projecting upward from the bottom head of the inner cryostat. Tapered guide pins will be installed in the bottom mounting holes of the TPC to engage the holes in the posts and guide the TPC into the correct position. Once the TPC is in the correct place, the guide pins will be removed and bolts will be installed to secure the TPC to the posts. The titanium plate for the upper PMT array will be guided from the inner cryostat near the main flange with tabs that allow vertical motion but constrain radial motion. Access for this work is from the top over the main flange. After these upper guides are secured, the TPC will be fixed in the vessel. The location of the weir surfaces that establish the LXe plane will be surveyed relative to known positions on the outside of the inner cryostat. This will allow rough leveling of the weir surface during future assembly steps. The next step is to stage the lid of the inner cryostat over the bottom and install a temporary safety support. The PMT cables, grid cables, sensor cables, and Xe gas lines coming from the upper PMT array need to be routed through a port in the inner cryostat lid. The sensors that monitor the position of the TPC relative to the inner cryostat wall will be installed and cables dressed. The lid can then be lowered onto the bottom of the inner cryostat and the large-diameter seal formed. This seal is designed as two seals (inner helicoflex metal seal and outer elastomer o-ring seal) to facilitate a check for leaks by pumping between the seals and looking at the rate of pressure rise. This rate can be comared to the baseline rate established during cryostat acceptance helium leak checking. All other ports on the inner cryostat must be sealed for transportation to keep the TPC clean. The cables will be wiped clean and tested for dust before they are pulled through a long bellows. The bellows will be sealed to the flanges on the ICV and leak-checked. The outer end of the bellows will be capped. The sealed inner cryostat will be pumped down to vacuum to ensure the seals are adequate. Other testing will be done at this point. This could include PMT functional tests, sensor tests, light-tightness tests between the skin and central TPC volume, and HV tests. A radon emanation test of the completed and closed vessel can be performed at this point. Closed-cell foam insulation and superinsulation blankets will be fit-tested on the outside of the inner cryostat for later underground installation. After these tests, the bellows will be dressed to the outside of the ICV and the ICV with TPC assembly will be double-bagged so it is ready to be moved underground. The special transport frame for this move will be brought into the clean room. The vessel will be rotated from vertical to horizontal using two hoists on the monorail and raised so the special transport frame can be placed beneath it. The vessel will be lowered on the special transport frame and secured for transport.

10.4.2.3 Underground Outer Detector Tank Preparation / Staging (Steps U1 – U2)

The first step of underground assembly is to prepare the water tank. All LUX components have been removed. Infrastructure work includes reorienting the overhead monorail crane so it runs North South. Some welding is needed in the water tank for attachment points for the cryostat support, the Gd-LS tanks, and the outer detector PMT ladders. New penetrations are needed for the HV umbilical, the heat exchanger (HX) conduit through the wall of the tank, and calibration tubes. After these welding operations, the tank will be passivated again to improve corrosion resistance to the pure water. The water tank will then be cleaned and made into a cleanroom with reduced-radon air delivered from the system located underground. The tank will be kept with slightly positive pressure to reduce air infiltration. The access door in the side of the tank will be outfitted with a temporary changing room and air lock.

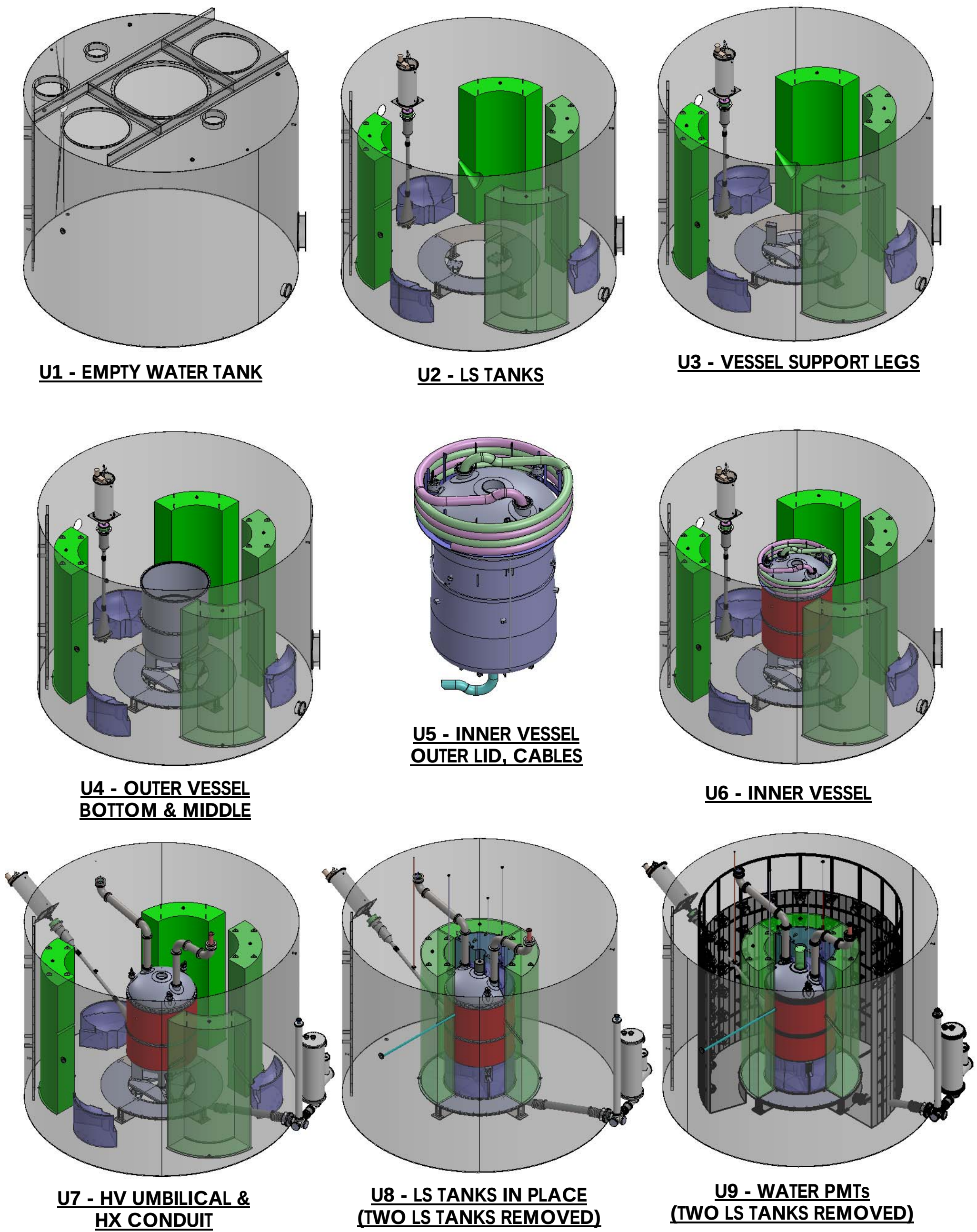


Figure 10.4.2: Underground installation sequence in water tank.

The central top port of the water tank is the only port big enough to allow installation of the Gd-LS tanks. Once the cryostat is installed, this path will be blocked. So the bottom and side Gd-LS tanks must be transported underground and staged in the water tank. Figure 10.4.2 shows the sequence of installation in the water tank. The Gd-LS tanks will arrive clean on the inside and covered with protective plastic and rigging frames. The acrylic tanks will be brought into the Yates headframe with a telehandler and set on a cart in front of the Yates cage. The four large side tanks will be moved first. Rigging will be used to attach the steel frame around the tank to the underside of the cage. The cage will be raised to lift the tank until it is vertically under the cage. A drag line will guide the lower end of the tank. The cage will be lowered slowly until the bottom of the tank is at the 4850L. A drag line will be reconnected to the bottom to pull the tank out as it is lowered further. The tank will be placed on a receiving cart, which will transport the tank to the entrance to the Davis Campus cleaning area (so-called cart wash). The external frame and external packaging around the tank will be cleaned to remove mine dust from transport. The bottom of the tank must enter the Davis area first. One hook from the monorail in the Davis Cavern will connect to two points near the bottom of one side of the rigging frame. A second hook from the same monorail will connect to the top of the tanks rigging frame. The motion of the hooks will be choreographed to lower the acrylic tank into the water tank, keeping the rigging vertical over the lifting points by moving the hooks along the monorail. Once the tank is vertical and set down on the floor of the water tank, it will receive a final inspection and leak test. The external packaging and protective plastic will be removed from the acrylic tank. A temporary beam with hoist will be installed to the inside top of the water tank to move the Gd-LS tanks inside the water tank and aid with unpackaging. The outside of the acrylic tanks will be cleaned with Alconox and water and visually inspected for any cracks. The three bottom tanks and the two top tanks will be transported inside the cage and unpackaged and cleaned in the cart-wash area. The three bottom tanks will be staged inside the water tank. The two top tanks will not be staged, as they will be installed from the top after the cryostat and cable-conduit installation is completed. Stainless steel support stands that hold the four tall outer Gd-LS tanks will also be staged into the water tank. The HV umbilical and parts for the HX conduit may also be staged in the water tank. A simple mockup that had the appropriate dimensions for the largest acrylic vessel transport frame was successfully lowered in the Yates shaft and partially transported underground.

10.4.2.4 Cryostat Transportation and Underground Assembly (Steps U3 – U6)

The installation of the cryostat starts with the cryostat support. The survey reference system for the detector will be established and a template for drilling the anchor bolts for the cryostat support leg will be located. Nine anchors will be installed into holes that are drilled and tapped into the thick steel shielding plates beneath the water tank. Once the anchor rods are installed, nuts will lock them to the floor. These nuts need to be seal welded to the bottom of the tank and the threaded rod so water can not leak out. This work will most likely be done during the modification to the water tank. Three machine leveling jacks will be place on the floor of the water tank temporarily. Three mounting plates will be installed onto the anchor plates and supported by the leveling jacks. The cryostat support legs, cleaned and triple-bagged, will be brought down in the cage. The outside bag will be removed at the entrance to the Davis Campus. The inside bag will be removed on the top deck near the opening to the water tank. The legs will be lowered into the water tank through the central port with a single hoist. The final bag is removed inside the water tank. The legs will be set into position on the mounting plated and loosely secured. The outer cryostat has been designed as three pieces so each piece can fit in the Yates cage. Each piece will be brought down in the cage cleaned and triple-bagged. The bottom head of the outer cryostat is lowered into the water tank with a single hoist and positioned over the three support legs. Once the bottom head is lowered, it will be bolted to the legs. The bottom section is then surveyed and located using the machine leveling jacks. Once it is in place, the other bolts and nuts are tightened. The final position is then surveyed for verification. The middle section will be brought in next, rigged into position above the bottom, sealed to the bottom, and leak-tested. The middle section will be surveyed to ensure it is level. Adjustment will be needed if it is out of range. A displacer around the outer cryostat cylindrical section reduces the amount of water between the Gd-LS tanks and the cryostat. This may be installed around the outer cryostat at this point or after the HV connection is completed. The top lid will be brought into the Davis Campus and staged on the top deck with its inner bag still in place.

The inner cryostat will not fit in the cage, so it must be hung under the cage. It will be horizontal for some of its journey from the SAL to the Davis Campus, and vertical for other parts. The TPC support system will be designed to accommodate support in both conditions and the transition between them. An external rigging company will be contracted to remove the ICV from the SAL and transport to the Yates headframe. It is anticipated that this move will also be done with a telehandler. There is a detailed plan for transport of the inner cryostat from the surface to the 4850L, described earlier in this chapter. On the 4850L, a special cart with air skates will be used to bring the inner cryostat from the Yates shaft to the Davis Cavern (this was the method used for LUX). The special transport frame must be cleaned. The outer bag around the cryostat will also be removed in the cleaning area. The transport frame will move the inner cryostat onto the deck near the entry hole to the water tank. The deck plates above the central hole of the water tank will have already been removed. A temporary platform will be built resting on the lower flanges of the beams that support the Davis deck. This temporary platform will be about 19 inches below the main floor. The platform is designed to roll along the flanges of the beam so it can be moved clear of the large port in the water tank. The two hooks on the monorail will be used to lift the inner cryostat off the transport frame, rotate it back to vertical, and rest it on the temporary platform. The bellows full of cables exiting the bottom of the cryostat will need to be managed during this lift. A temporary cleanroom will be built around the inner cryostat. Reduced-radon air from the underground system will be used to provide a clean atmosphere. The inner bag around the inner cryostat will be removed. Closed-cell foam insulation will be installed onto the sides and bottom of the cryostat. The LXe weir drain lines will be connected and routed. The cryostat cooling thermosyphon evaporators will be attached to the fins on the cryostat walls. Temporary supports for the outer cryostat lid will be installed onto the inner cryostat. The outer cryostat lid that was previously staged will be unbagged, rigged over the inner cryostat, and set on the temporary supports. The two upper bellows will need to be guided through the ports in the outer cryostat lid as it is staged. The permanent support rods that hold the inner cryostat from the outer cryostat will be installed. The supports will be adjusted to position the weir surface of the inner cryostat parallel to the sealing surface of the outer cryostat lid. Then prefabricated superinsulation blankets will be installed. The lower section of the three calibration ports will also be installed. The outer cryostat lid will then be lifted and the load from the inner cryostat will transfer from the temporary supports on the deck to the permanent supports from the lid. The temporary platform will be rolled along the flange of the beam until it is clear of the water tank opening. The assembly of the outer cryostat lid and inner cryostat will be lowered into the water tank and into the outer cryostat bottom. As the inner cryostat is lowered, the bottom bellows will need to be threaded through the central port of the outer cryostat bottom head. The reduced-radon air will again be flowing into the water tanks for this process. The crane will set the assembly down so the outer cryostat lid rests on the outer cryostat middle-section top flange. The inner cryostat will still be hanging from the lid. This flange can then be assembled and leak-checked.

10.4.2.5 Utility Connection (Step U7)

The lower cable bellows are routed to the edge of the water tank through a vacuum jacket. Xe transport lines have a separate vacuum jacket and connections will be made with an orbital welder whenever possible. Some connections may be made using VCR fittings. These lines continue through the outer wall of the water tank to the cryo tower. The lower PMT cable conduit continues vertically after penetration of the water tank wall and connects to the breakout box. The cables continue into the breakout boxes and connect to an array of flanges and hermetic feed-throughs. The upper bellows will be routed through vacuum jackets to the appropriate flanges on the top of the water tank. One bellows connects to vacuum pumps and Xe recovery system plumbing; the other connects to another breakout box with an array of flanges and hermetic feed- throughs. During the connection of the cables in the breakout boxes, reduced-radon air will be routed through the ICV to prevent back diffusion of mine air into the ICV. This area has many details that must be carefully planned.

The HV umbilical attaches to the large side port. To reduce krypton and radon absorption by the internal plastic components, this assembly will also be purged with nitrogen or reduced-radon air whenever it is opened. The HV umbilical is a flexible assembly that connects to the top of the water tank and the side of the cryostat. The central cable of the umbilical needs to be electrically connected to the cathode. The inner tube of the umbilical then seals against the inner cryostat. The flange will have a double seal (inner helicoflex and outer o-ring) so it can be leak-checked at this point. Then the outer vacuum jacket will slide down toward the detector and make a seal to the outer cryostat. This seal will have a double o-ring so it can be leak-checked. Sealing rings at the water tank wall are installed to seal the inner tube to the outer tube and the outer tube to the vacuum tank. There are no direct water-to-Xe seals.

The final step of cryostat installation is positioning and leveling. The connections for the conduit and HV umbilical add load and positional constraints to the hanging inner cryostat. The support rods will be adjusted using feedback from built-in electronic level sensors. We have designed in enough compliance to these connections so the inner vessel can be moved. The cryostat should now be sealed and the reduced-radon air flow can be stopped. The inner cryostat will be pumped down to start long- term outgassing of the internal plastics.

10.4.2.6 Outer Detector Assembly (Steps U8 – U9)

The Gd-LS tanks can now be placed into final position. The three bottom tanks are set on platforms connected to the cryostat legs. The upper Gd-LS tanks are then installed through the top port of the water tank. They are lowered slightly radially outward from their final positions to clear the PMT cable conduit and thermosiphon conduits and, once they are low enough, translated under the conduits to the correct final position. The upper Gd-LS tanks are supported by the top flange of the outer cryostat. The four side tanks will be moved in adjacent to the displacer around the outer cryostat and rest on stainless steel supports. There are notches for the HV umbilical so the tanks have to come in from the proper direction. After positioning, the tops of the tanks are connected for stability. Each tank is secured so it will not float in the water or tip over in an earthquake. Each tank has a fill line and vent line that come to a common overflow reservoir on the top of the water-tank lid. The final system will be visually inspected and leak-checked with a low-pressure gas.

The outer detector PMTs will be installed onto half-ladders and lowered into the water tank through one of the larger off-axis ports in the lid. The half-ladders are assembled together and secured to the roof and floor of the water tank and cables are run up to one of the top water-tank ports. Cables are sealed at these ports. The Tyvek reflectors that direct light lie on the floor, are hung vertically from the top of the ladders, and are stretched across the top of the ladders.

The detector is now ready to be filled with Xe, Gd-LS, and water. Xe filling must wait until the inner cryostat has been at vacuum long enough to get the residual gas content of the plastics to an acceptable level. Warm low-pressure Xe gas may be circulated to heat the plastic and enhance diffusion. This Xe would be pumped out and repurified or sold. Once plastic outgassing is at an acceptable level, the vessel will be filled with Xe gas and slowly cooled with LN2 until the Xe starts to condense. Filling continues until the Xe liquid is at the desired level. Gd-LS is received on site ready to use in 55-gallon drums, temporarily stored in the SSF. The Gd-LS and water must be filled at the same time to minimize stress on the acrylic walls. The levels do not need to match exactly, so one drum of Gd-LS can be added to the tanks one at a time as the water level rises. It is added by pressurizing the drums with nitrogen gas to force Gd-LS through the filling tubes at the overflow reservoir. Water is purified before it is added, and covered with a nitrogen head once the tank is filled. A flowing nitrogen head is maintained over the Gd- LS to protect it from both radon and oxygen.

While the main detector installation and assembly sequence described above are occurring, the support equipment and utilities for the experiment will be installed in Davis. This includes cryogenic cooling equipment, vacuum pumps, LN_2 thermosiphons, Xe purification and circulation equipment, TPC HV supplies, PMT readout electronics, PMT HV supplies, calibration source tubes, connections and hardware, the emergency Xe recovery system, DAQ, and control systems. Details of these items are covered in other chapters.

The duration of the work in the SAL from the start of the assembly of TPC to the inner cryostat being sealed and ready to move underground is expected to be about seven months. Before underground installation work can begin, LUX must be decommissioned and removed (by very early 2017) and Davis infrastructure work described earlier in this chapter will need to be completed. LZ installation underground has an estimated duration of seven months from staging of the Gd-LS tanks to being ready to fill.

10.5 Bibliography

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